Layer 0 Module Support and Cooling

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on behalf of the Super-B SVT Group

Outline

- Microchannel Full Module support design, test results .
- Microchannel Net Module construction and and test .
- Net Module Simulation Study
- Further developments to reduce X_0 and improve thermal efficiency.
- Conclusions

Support Characteristic

Merging Super-B experiment specifications with the thermal and hydraulic concepts, we focused our attention on a CFRP supports with microchannel technology for an heat evacuation through a single phase liquid forced convection .

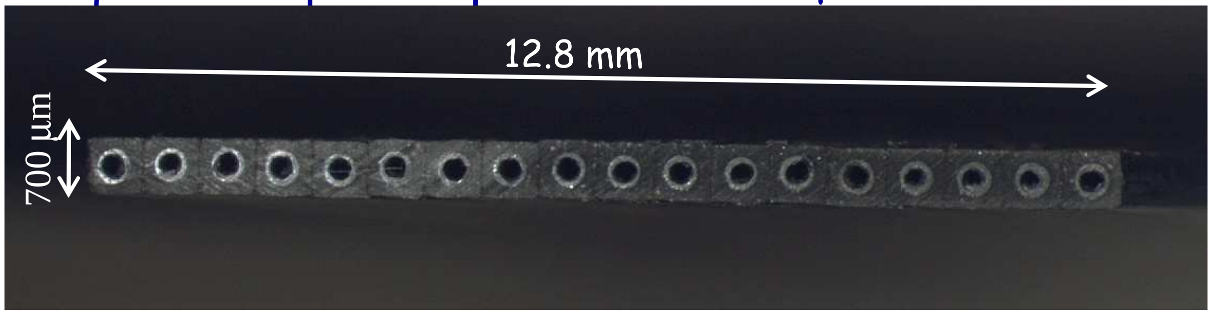
Several prototypes with different geometries and material have been realized; miniaturization of composites structures have been developed through close collaboration with companies. Prototypes have been submitted to test at the TFD laboratory of the INFN-Pisa.

Main goal : reducing as much as possible X_0 maintaining good cooling performance!

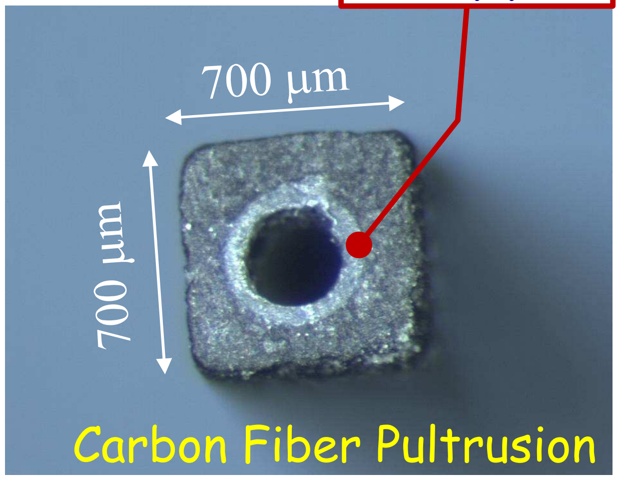
Module support

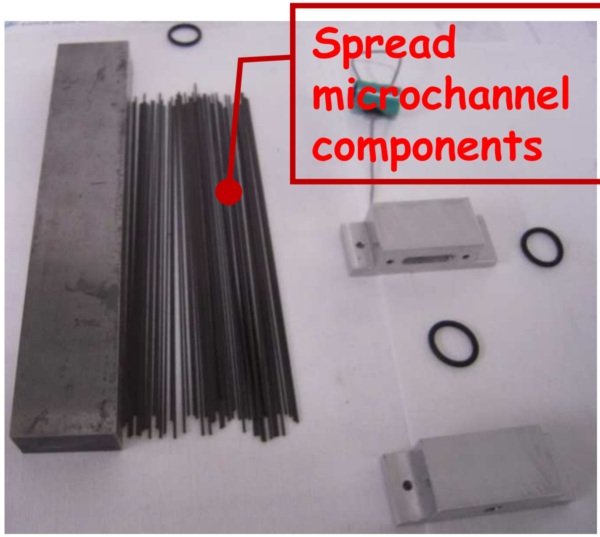
CFRP MICROCHANNEL MODULE

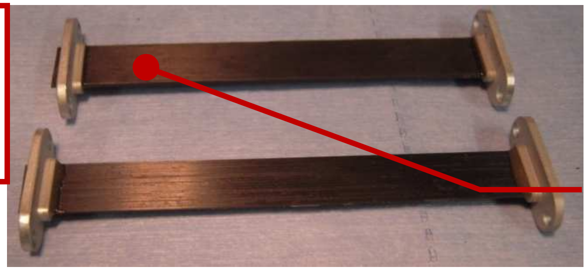
Obtained with additive method by pultrusion C.F. TohoTenax HTS 40 , gluing in special masks, side by side, 19 single microtube.
The inner diameter of the peek microtube is 300 μm, the thickness of the square composite profile is 700 μm .



Peek pipe







Support Module assembled

The total radiation length of this module is 0.28 % X_0
An internal peek tubes 50 μm thick is used to avoid moisture on carbon fiber.

X_0 module support improvement

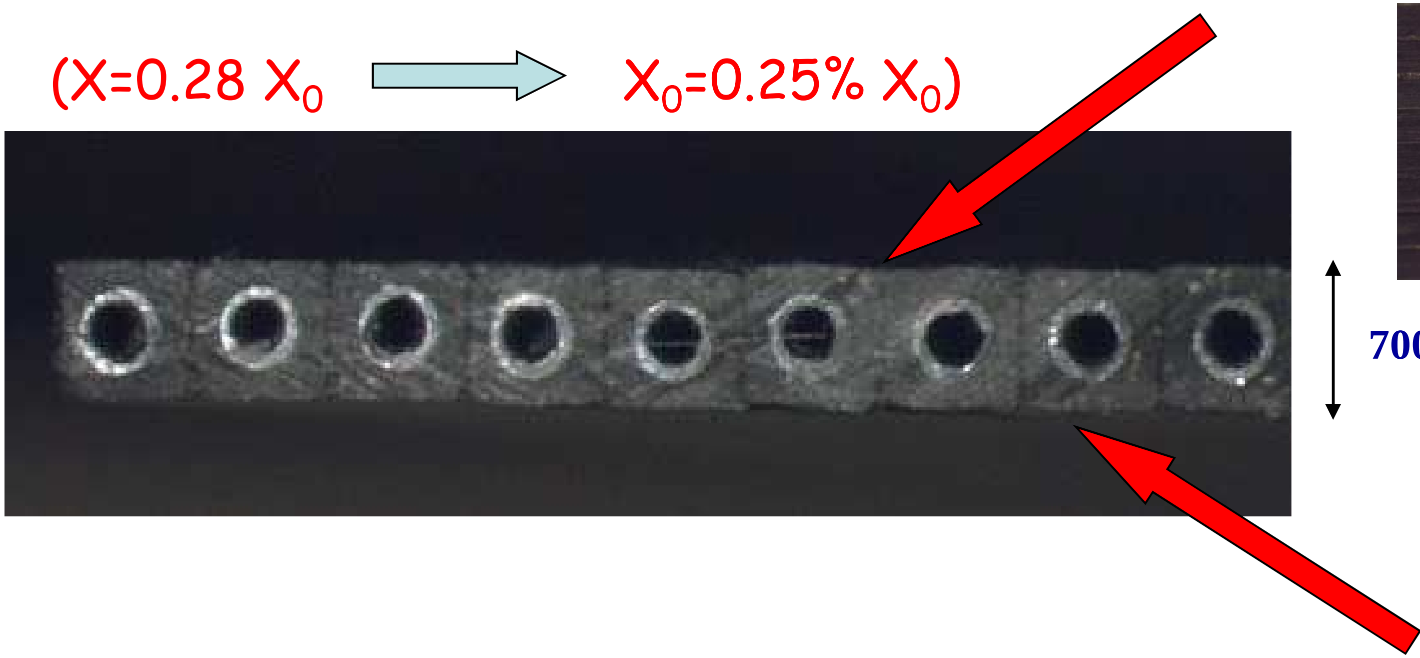
Planarity tollerance of the microchannel module is 40 µm .

Grinding about 40 µm on the top and bottom surfaces of microchannel module obtained a 620 µm-thick structure with further 15% reduction in X_0 .

better thermal interface between CFRP and the Aluminum-kapton foil (ground layer of the silicon detector).

Surface roughness

(X=0.28 X_0 → X_0=0.25% X_0)

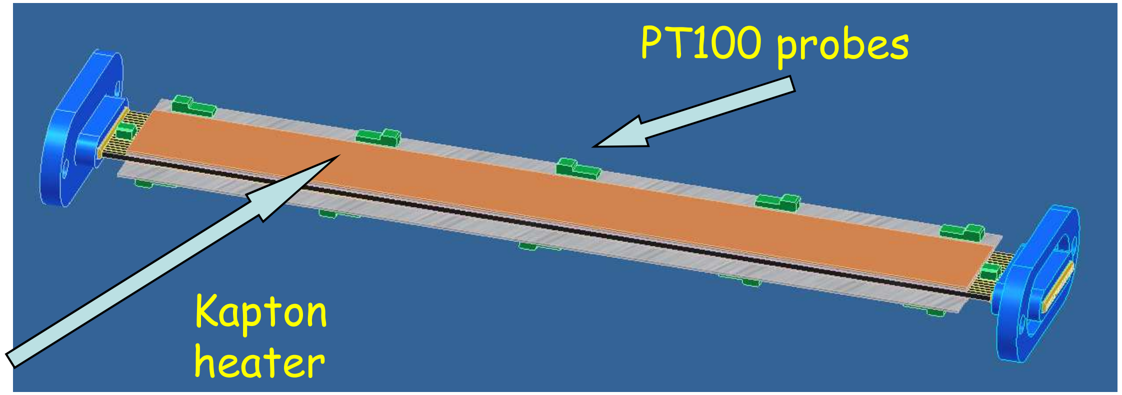


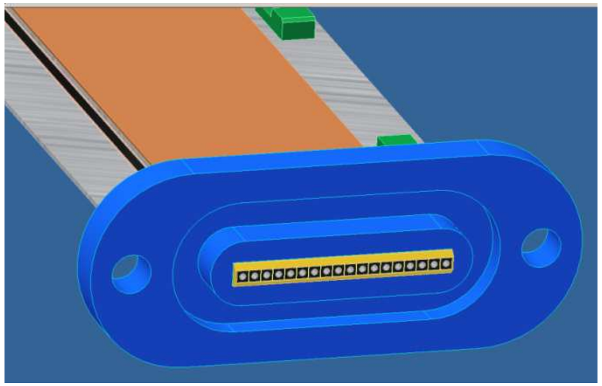
700 µm → 620µm

Surfaces to grind

Module Samples

A kapton heater is glued on the CFRP support structure to dissipate the needed power density.
On the bottom of the heater there is an aluminum foil 300 μm-thick, in place of the silicon detector. On the top, to read the temperatures, n.5 PT100-probes are glued, positioned just laterally to the heater.
An Aluminum kapton 75 μm-thick is sandwiched between the support structure and the aluminum foil, simulating ground plane in the real detector. There is also a glue layer between each components (30μm-thick on average).



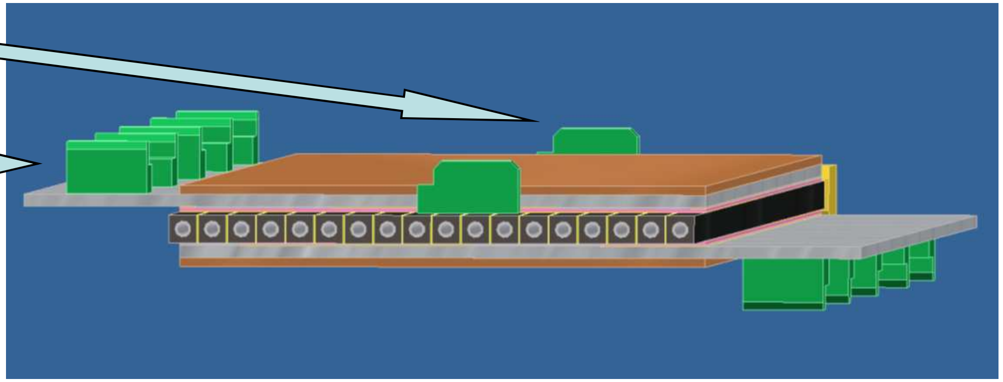


There are two kinds of tested configurations: the "double side", where the heat is dissipated both on the upper and the lower external faces, and the "single side" where the power is dissipated only on the upper face.

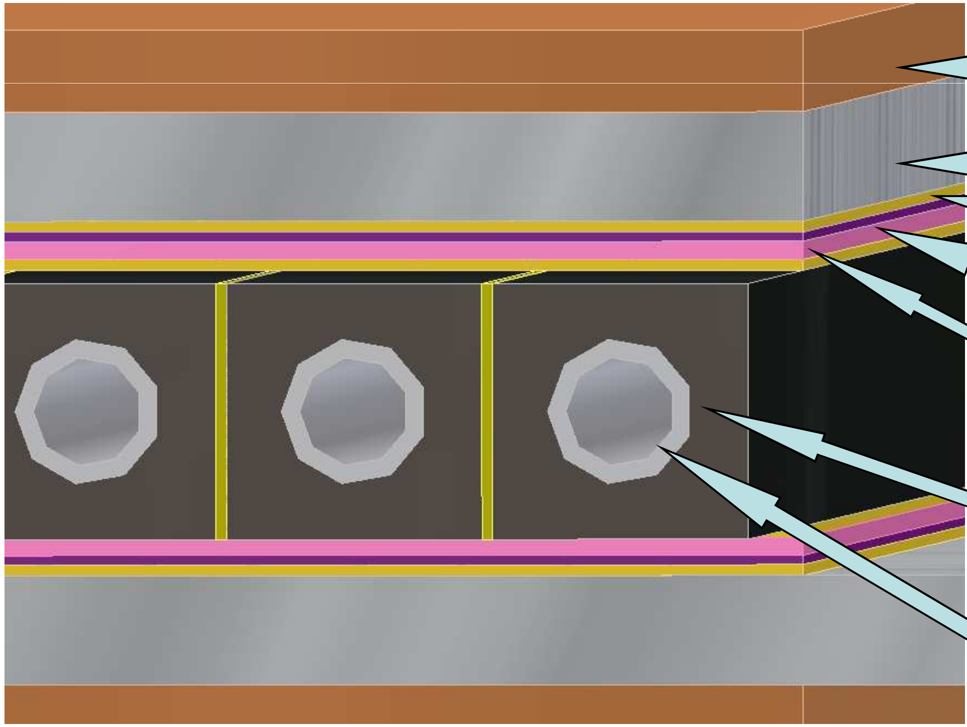
Module Sample Structure

N°2 PT100 temperature probe on CFRP

N°5 PT100 temperature probes/side on Aluminum



Double side configuration (cut view)



Kapton Heather 220 μm

Aluminum foil 300 μm

Glue 25 μm

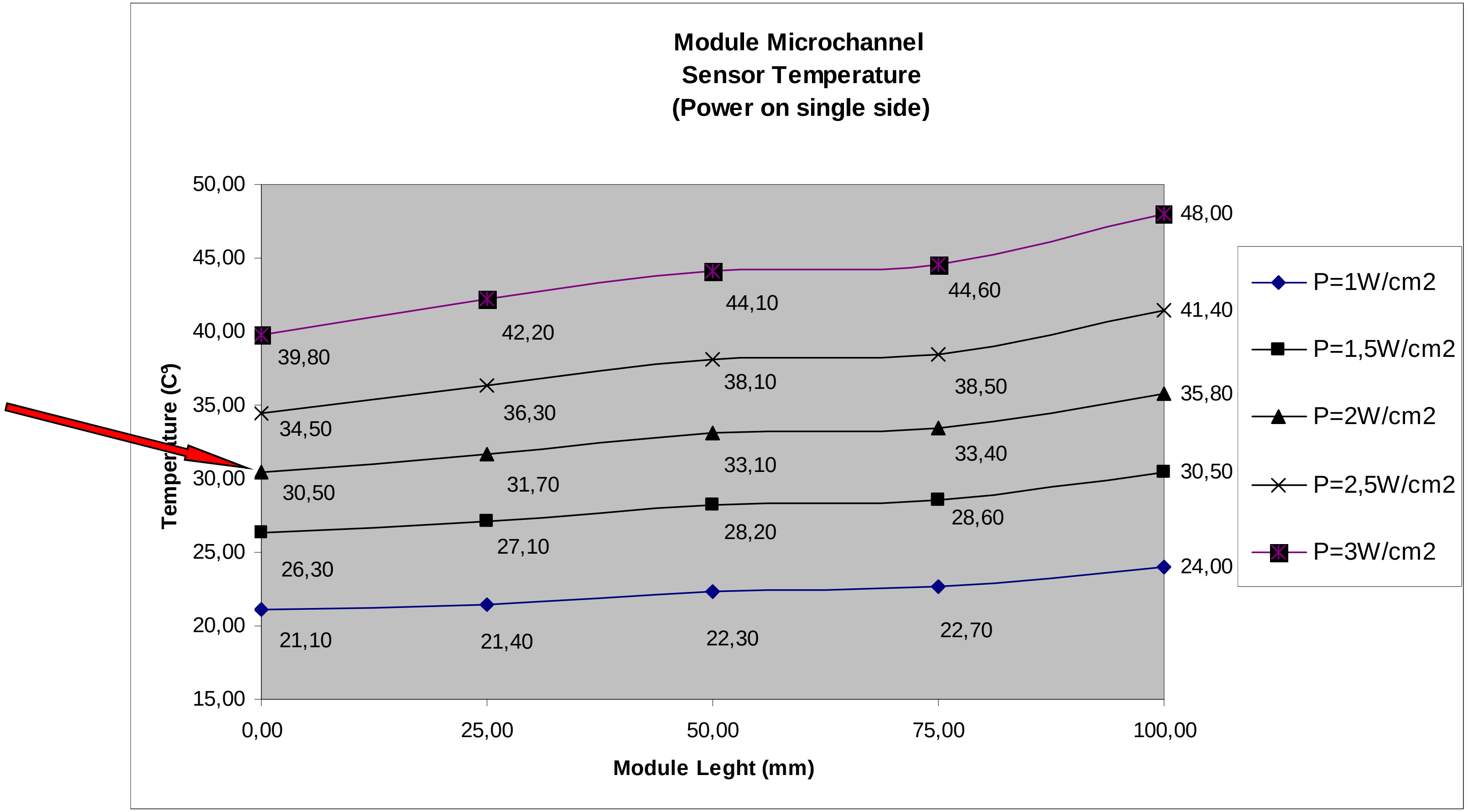
Kapton+Aluminum 50μm +10μm

Glue 25 μm

CFRP microchannel Th=700 μm

Peek Tube/Di=300 μm, th=50 μm

Test Results



Temperature along the module (ΔT = 5 °C)

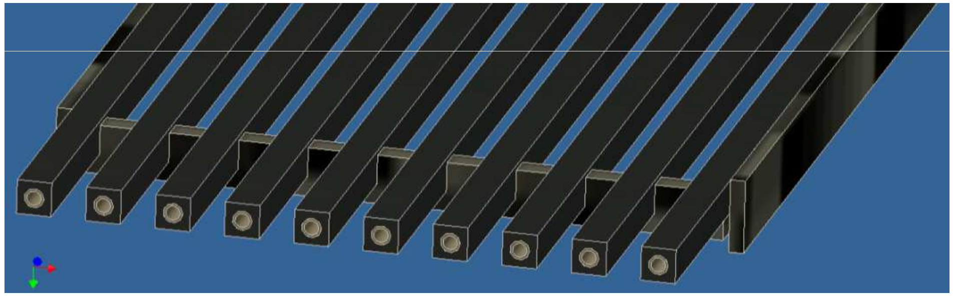
Net Module support

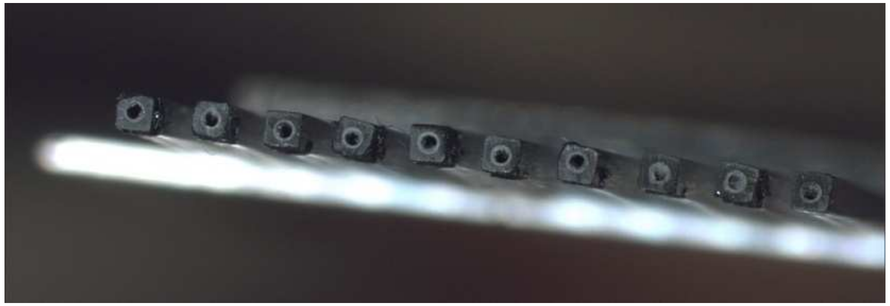
Assuming further progress in MAPS sensor design, and looking to actual hybrid pixel, the required Power (analog + digit), could step down to 1.5-1.0 W/cm^2.

We choose to design a lighter solution for the support structure .

The Net Module is a micro-channel support with vacancies of tubes in the structure .

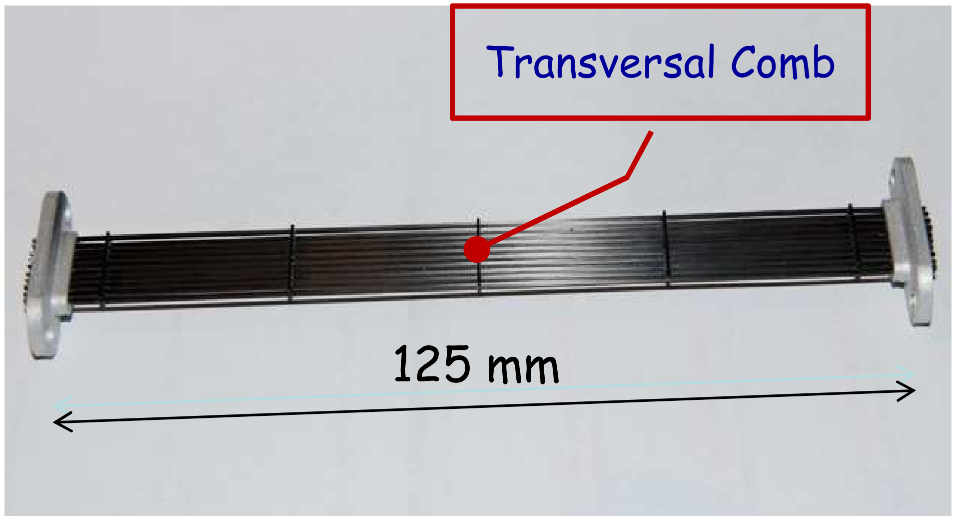
We admitted worse cooling performance for strongly gaining in X_0.

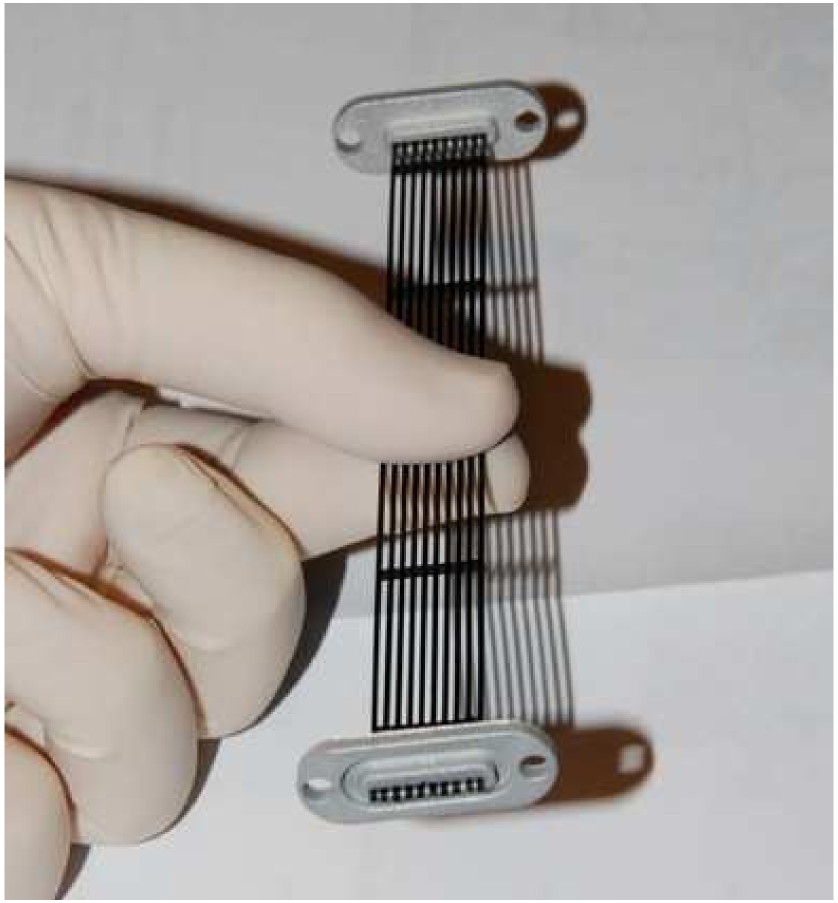




Material of the support structure: (CFRP + peek tube + Water + CFRP Stiffeners)

Net modules support

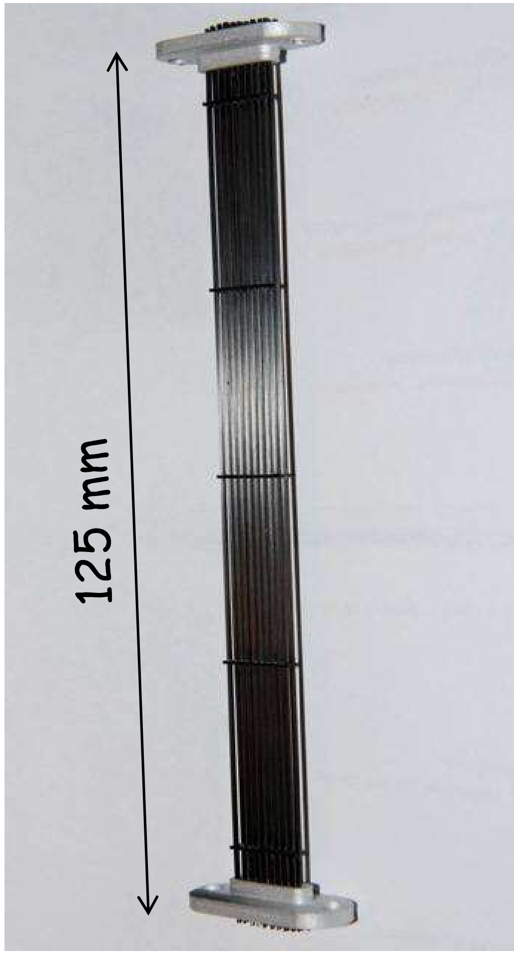


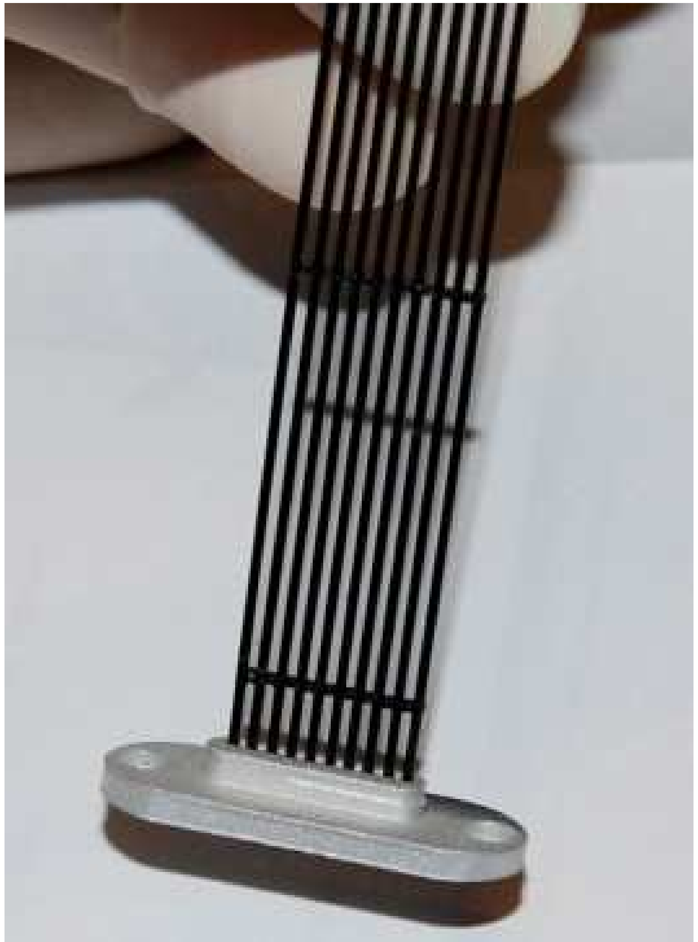


N.2 Prototype produced !

Net module mechanical structure:
10 microtube + 5 trasversal comb

Net module support





Epoxy glue used to place microtube on very thin transversal CfRP stiffeners.

Micropositioning and microgluing work required a dedicated gluing mask!

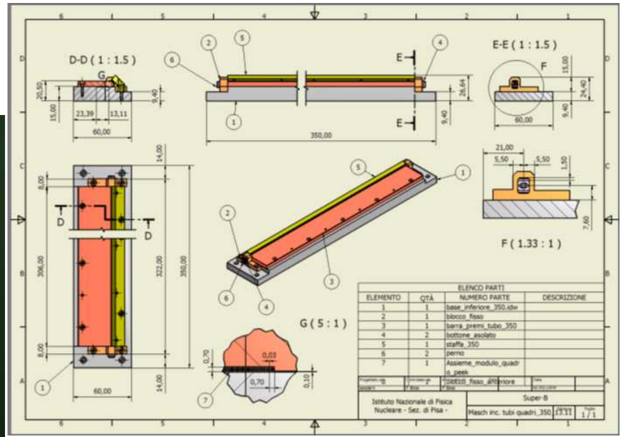
Sealing of the hydraulic interface obtained with epoxy/CFRP .

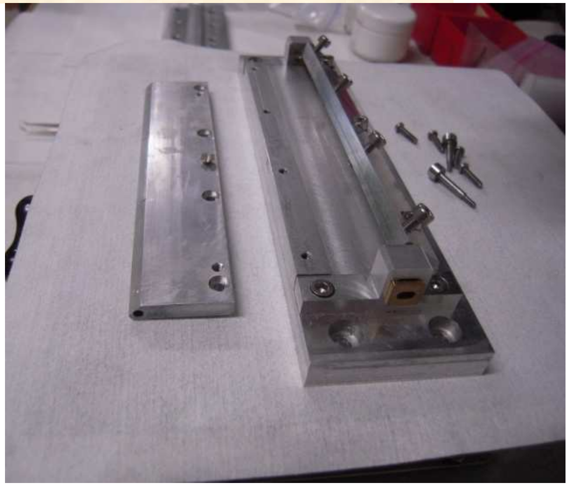
$X = 0.15\% \ X_0$

The Net Module has the same hydraulic parameter / microtube , already measured for Microchannel module.

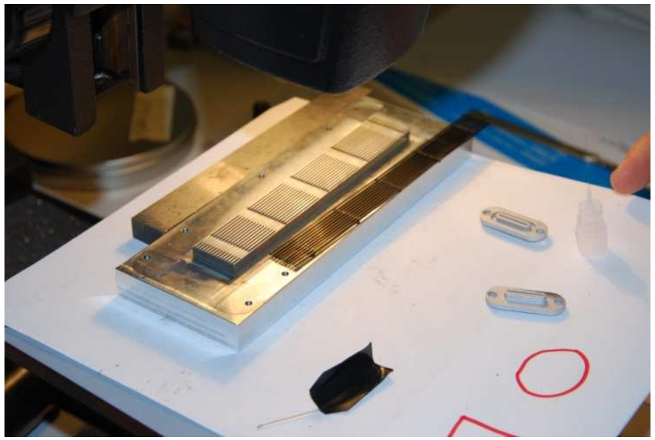
Tooling Construction Activities

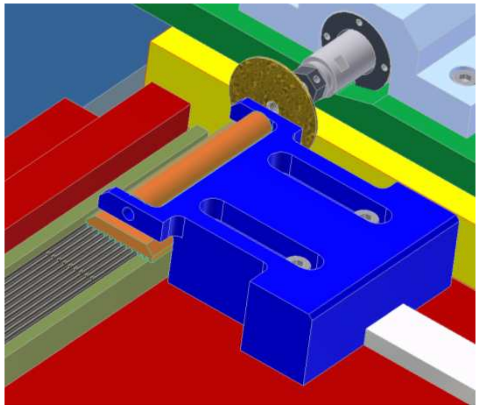
Module Gluing Mask



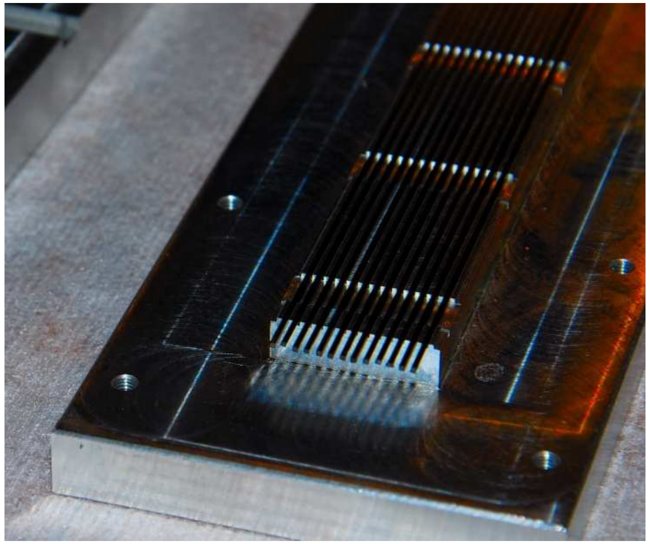


Net Microchannel
Module Support
high speed Saw





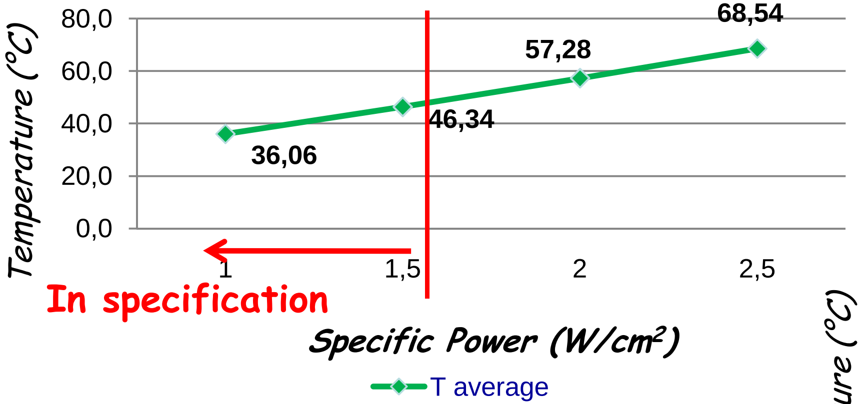
Tooling Construction Activities



Mask for 100-300 mm length Micro-channel Net Module

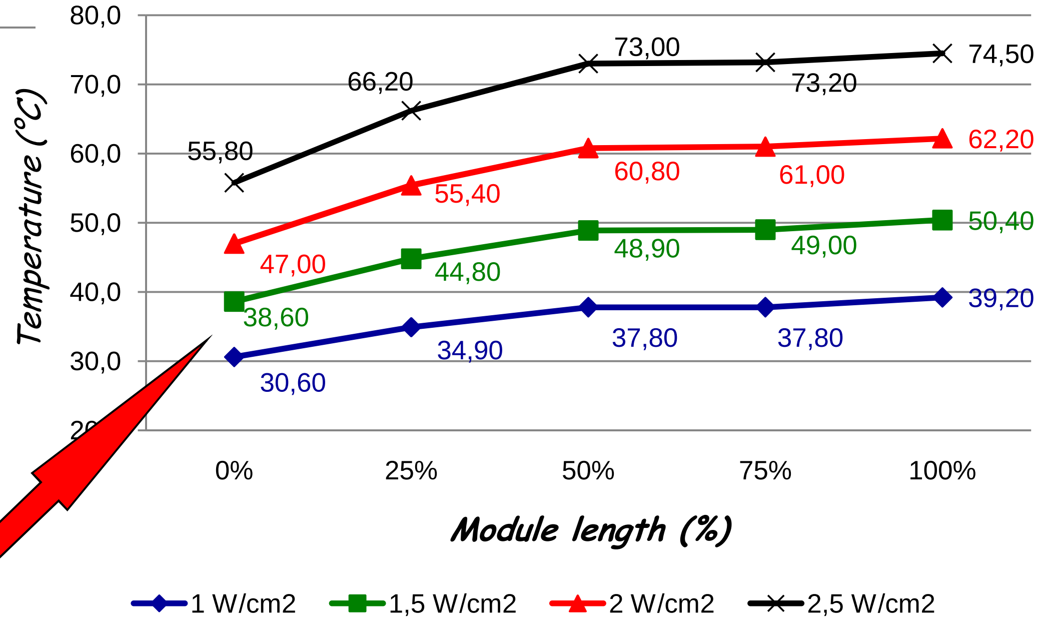
Net module test results

Net module average Temperature Vs. Specific power density Power on Single Side



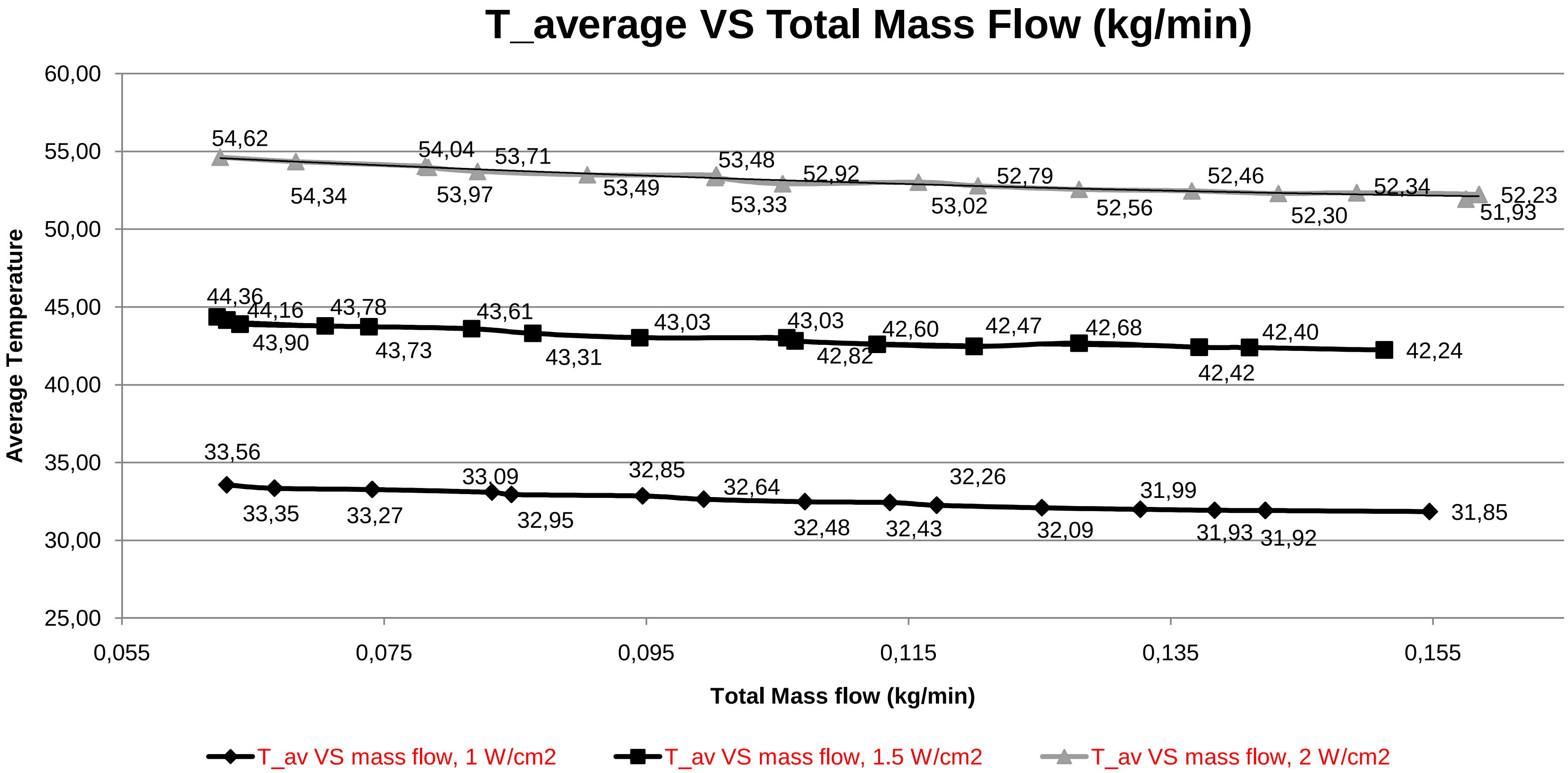
Tests performed with water-glycol @ 10 °C as coolant.

Net module, Sensor Temperature Power on Single Side



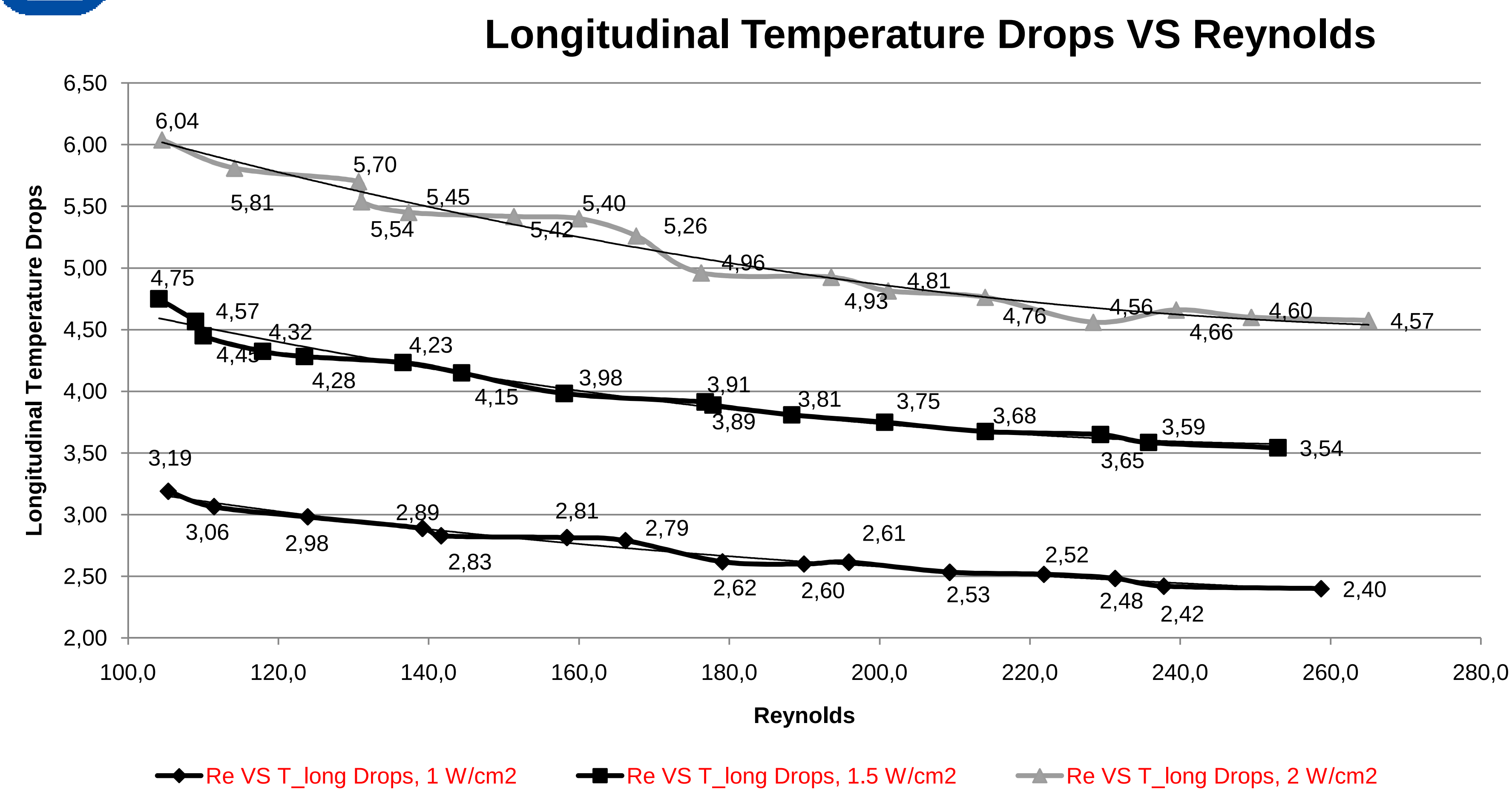
From this experimental data, the Net Module is able to cool power up to about 1.5 W/cm² at the max required Temperature (50 °C). This goal can also be achieved with a greater safety factor by reducing the inlet coolant temperature.

Net module test results



Increasing the total flow from 0.06 kg/min to 0.16 kg/min -> gain ~2 ÷ 2.5°C in Temperature.

Net module test results



In order to decrease the longitudinal temperature drop along the module (Difference between T_{input} and T_{output}) is possible to increase the Reynolds number, that means increase the fluid velocity.

Remark: This means the pressure drops grow significantly!!

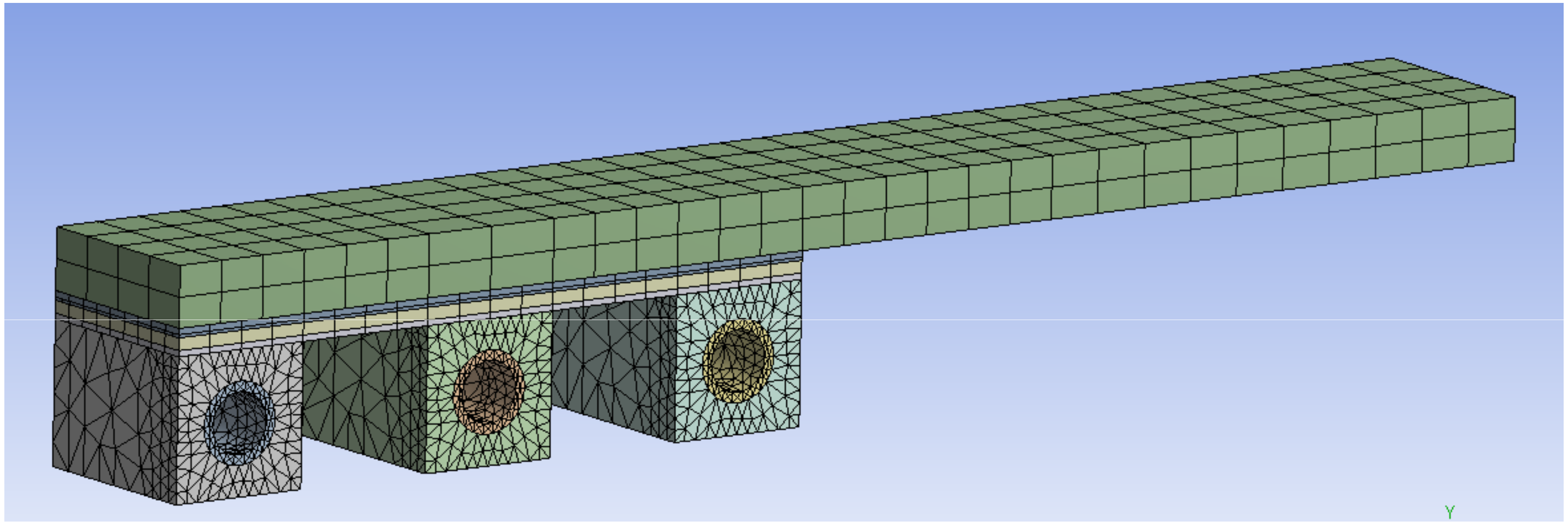
Hydraulic parameter

The hydraulic parameter shows that for the microchannel geometry there is a laminar flow and a good thermal film coefficient (h)

	Total Section	D_h	Total flow	Pressure drop	Flow characteristic	Fluid velocity	Re	h
	mm^2	mm	kg/min	atm	-	m/sec		W/m^{2}K
Net Module Microchannel	0.7065	0.3	0.128	3,612	Laminar	3,37	267	3275
Full Module Micro channel	1,272	0.3	0.244	3,612	Laminar	3,37	267	3275

Thermal Simulation

In order to validate the experimental tests we have been performed simulation studies on the Net micro-channel Module .



Boundary conditions values:
Power density: 1 W/cm2
Water film coefficient*: 3275 W/m2K
Coolant Temperature: 10 °C
Air film coefficient: 5 W/m2K
Air Temperature: 22 °C

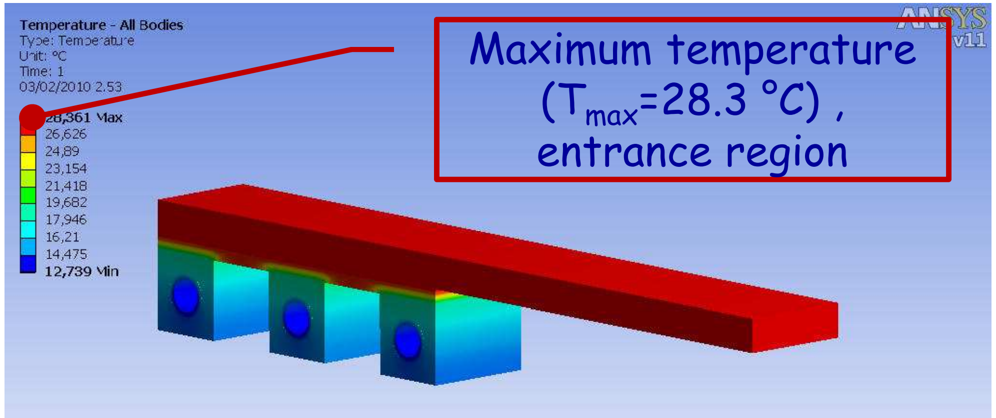
Thermal conductivity of the materials:
CFRP: 2 W/mK
PEEK: 0.25 W/mK
Kapton: 0.15 W/mK
Aluminum: 210 W/mK
Glue: 0.22 W/mK

*: it is derived from experimental and geometrical data.

Net pixel module simulation results

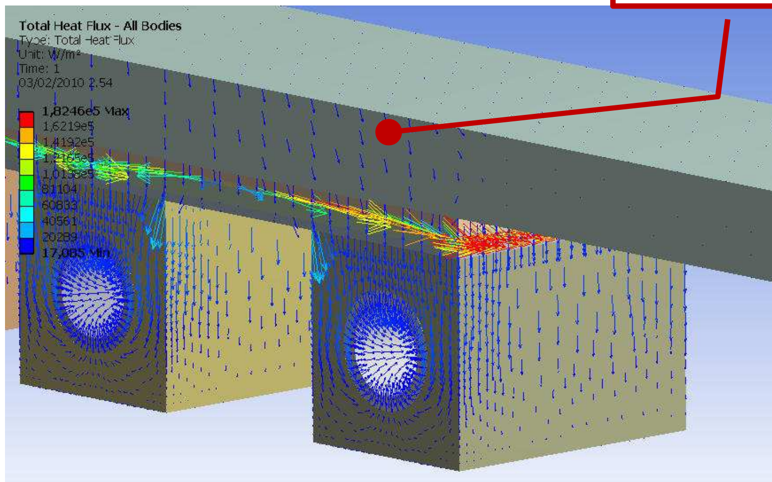
Case study: 1 W/cm^2 (the same Boundary values used for microchannel module)

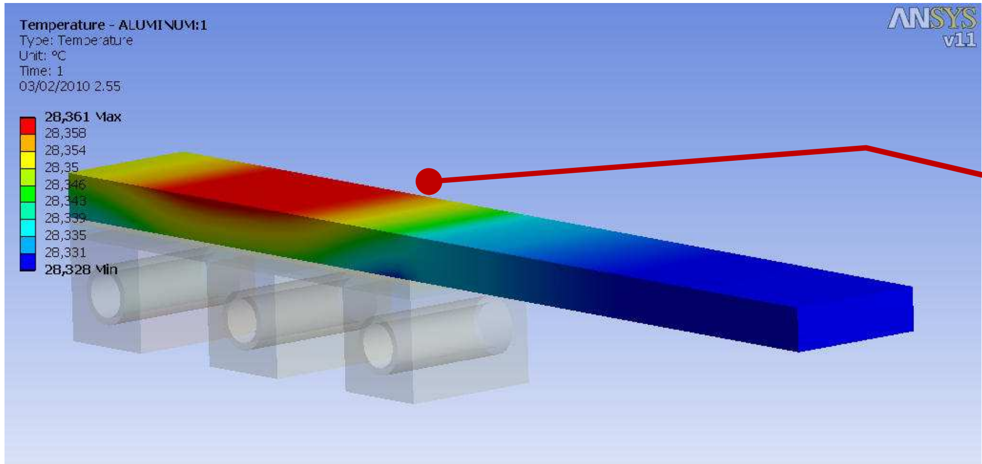
We consider the entrance region of the module.



Maximum temperature (T_{max}=28.3 °C) , entrance region

Heat flux





Temperature gradient (0.4 °C) on aluminum.

The ~ 2 °C difference between FEA results and experimental data can be ascribed to the uncertainty of the thermal interfaces.

Module Support performance improvement

There are several lines to follow for further enhancing the performance of the microchannel support:

1) Further miniaturization of the base microtube profile:
CFRP thickness = 500 μm, peek tube inner diameter = 200/50 th μm.
(at present we are developing prototypes with the companies: it is possible but it is difficult !)

2) Use of thermoplastic technology and/or composite material with higher conductive thermal coefficient.
(collaboration with companies needful)

3) Opposite flow directions of the coolant in the module in order to minimize the temperature variation along the module
(feasible: it requires a special design of the hydraulic interfaces)

Net Module

Remarks :

The Net Module is a support structure well suited for variable specific power request .
In fact it is possible to build a structure by adding single microtubes according to the sensor power amount, with means minimum material budget without change dramatically the design of the project.

Conclusion

• We performed studies for a light mechanical/cooling support structure suited for the L0 of the Super-B experiment and in general also for detectors with high power dissipation in the active region (order of 2 W/cm^2).

• Our prototypes design for the L0 Super-B detector, based on microchannel technology ins ingle phase forced convection, matches the requirements for pixel MAPS (P= 2W/cm^2, X_0= 0.25%) and for pixel hybrid sensors (P= 1.5-1,0 W/cm^2, X_0= 0.15%) .

• Further enhancement are still possible within this technology, gaining in X_0 and thermal efficiency.

BACK UP

Test Procedures

The power dissipated by the kapton heater could be tuned from 1.0 to 3.0 W/cm^2.

The tests have been performed in standard way for both kinds of module. During the tests the average temperature of the environment was 22.0 °C (for these kind of test there is no need to avoid environment free convection and irradiation).

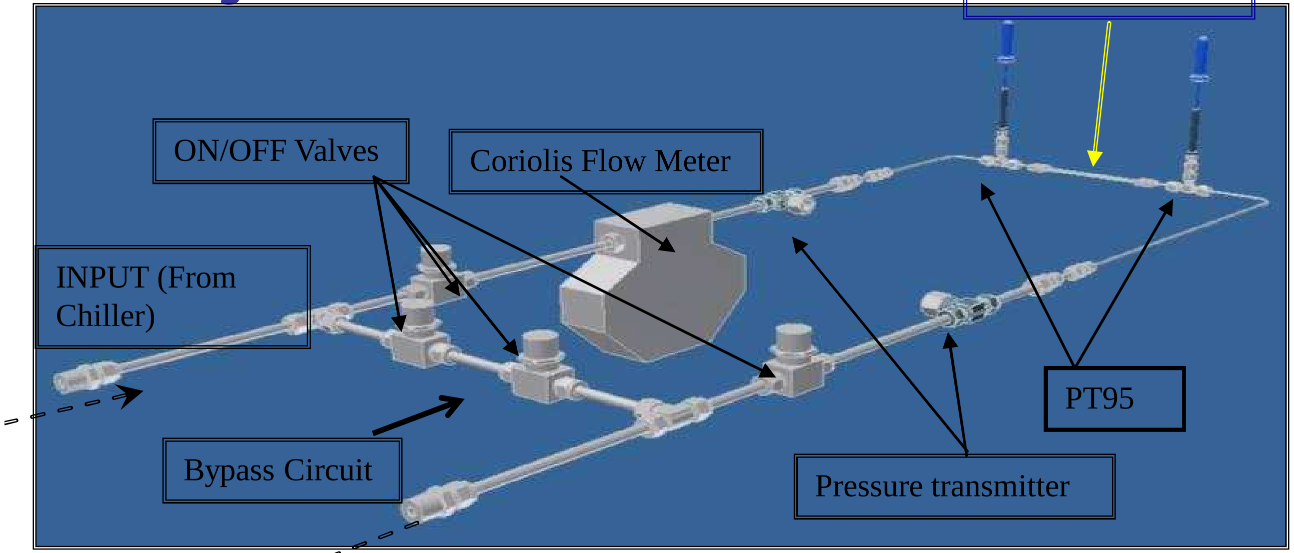
The test was performed by setting the fluid pushing pressure 1.5 atm, the (suction) pressure 0.5 atm, the fluid temperature 10 °C. The electrical power was then switched on and set to the lower specific power (1.0 W/cm^2). The maximum pressure was set 3 atm and the heater power tuned up according to the experimental program (1.0 to 3.0 W/cm^2)

In all conditions, the DAQ system is able to record up to 24 parameters at the same time.

Test and set-up at TFD lab

Cooling Circuit Schematic View:

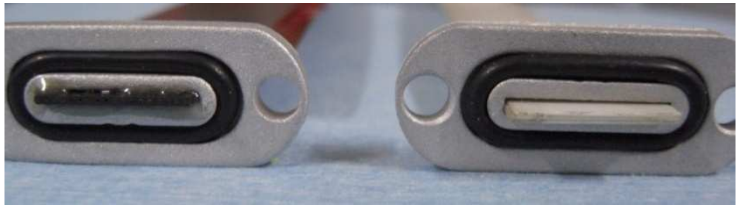
Test Section

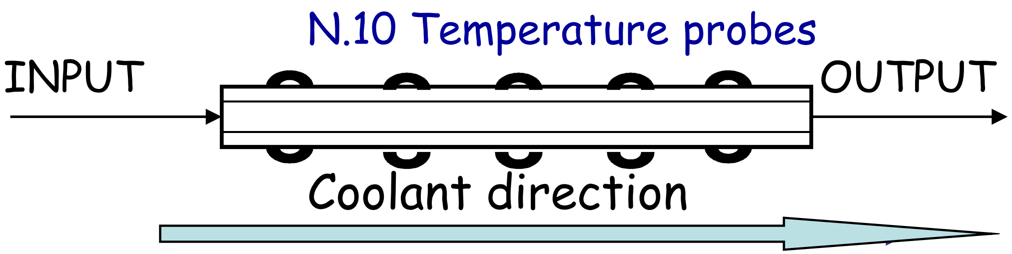


OUTPUT (To the Chiller)

DAQ System:

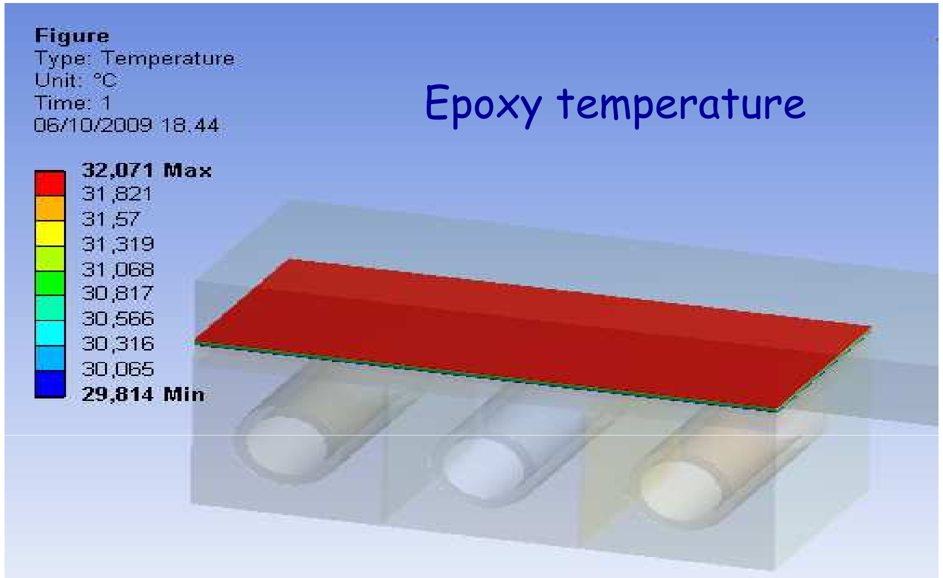
Test Section:

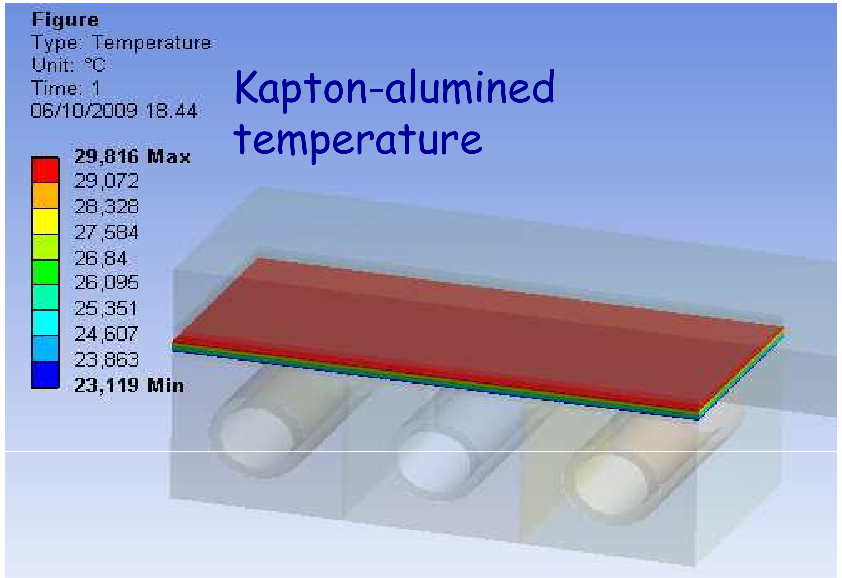




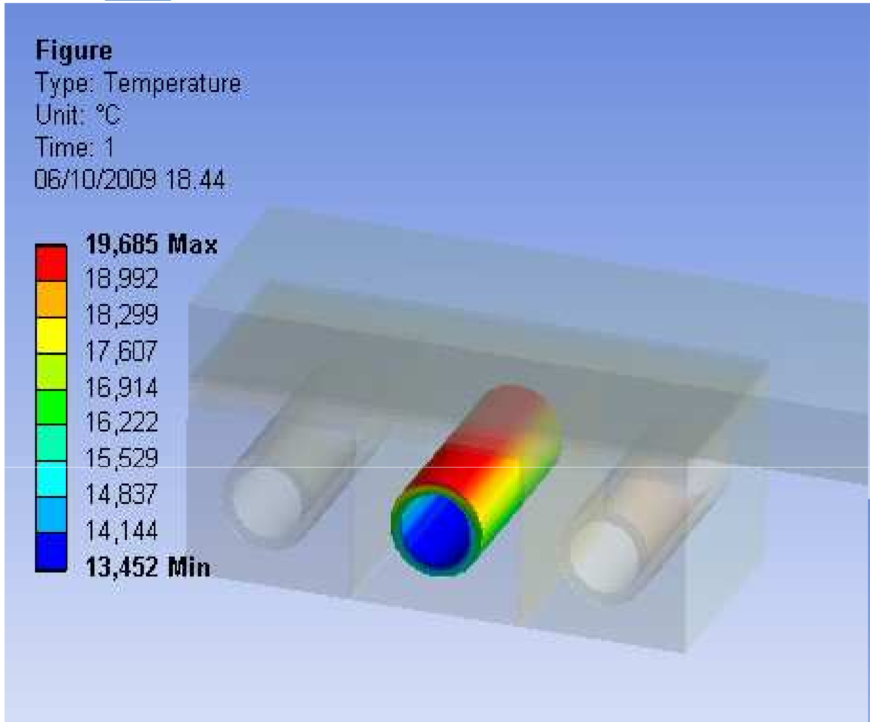
Longitudinal sample section

Thermal Simulation

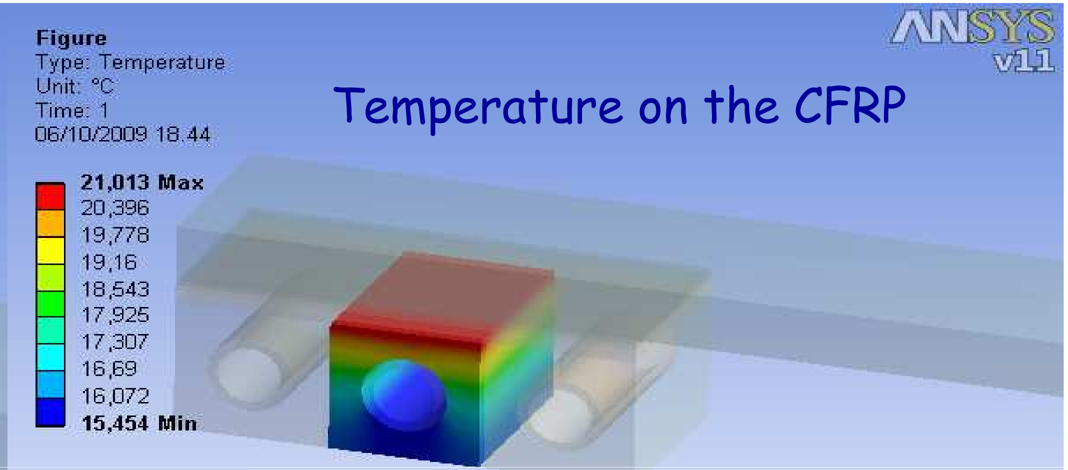




Thermal Simulation



Peek tube temperature



Temperature on the CFRP